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Virtual pilot algorithm for vehicle control

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Abstract— **Nowadays, more and more driving assistances are available to help the driver and to improve the vehicle handling. With increasing sensing capacities, it also becomes possible to have a local view of the vehicle surrounding. Hence, the next steps are to provide the driving assistances a supervisor that schedules all the possible actions and plane trajectories. In this article, we propose a decision method that fits the driver decision and action schemes. The system is at three levels, for action, decision and long range planning. the article is focused on the second layer and the interaction with other layer. The second layer algorithm, based on risk assumption, evaluates, in the vehicle vicinity, the risk related to each detected object. It then computes possible actions for lower level layer. The developed method is constrained by the future implementation on a vehicle : low computation time available and small memory size.**

I. Introduction

Even with the introduction of driving assistances, the number of fatalities remains high. Most of these fatalities result of driver errors, which could be slow road departure, because of driver drowsiness or inattention, or fast road departure, because of driver low experience or high speed. Whatever the scenario of car accident, in existing driving assistance, the driver remains the sole responsible of the driving task. With the increasing development of technologies, it becomes now possible to provide more intrusive driving assistance, for instance longitudinal control with ACC[1], at highest security level. Since the demonstrations on Californian Highway at the end of the 90s, which prove autonomous driving on secured environment (dedicated lane on highway with magnets), most of the works focus on interaction with driver. Recent European project SPARC, [5] provides a safe way to interact with driver both on longitudinal and lateral control. Using these developments, it is now possible to offer to the driver new concepts of driving assistance. They will sense the environments and monitor the driver actions in order to compare a set of safe trajectories computed by the assistance and the realization done by the driver. When the difference between the safe set of trajectories and the realization is too high, the system can decide to act on the driving task.

Using this concept, many field of research must interact to develop the driving assistance : interaction with the driver, path planning of the vehicle, vehicle control, environment sensing...

[1]ACC : Automated Cruise Control

In this article, we focus on the definition of which manoeuvre is safe with respect to the environment. In order to define a safe trajectory or a safe manoeuvre, approaches developed in [3] combine the environment sensing and control task directly inside the path generator. However, this approach and their developments requires high computation, which is not compatible with vehicle on board system. Vehicles that do a path planning to determine the safe trajectory already exist, as CyberCars [4], but the path planning is realized in an environment with low interaction with other objects and at a low speed. Vehicles involved in DARPA Challenge must elaborate their trajectory with a more complex environment, but the sensors used, the computation, ... are not realistic with respect to the price, energy and computation in car. Moreover it does not interact with the driver as they only deal with autonomous system.

Some of the drawbacks of existing methods are the high computation time, the high memory usage and the lack of interactions with a possible driver behind the steering wheel.

Our approach aims to remain close to the driver and to use already available system to control the vehicle : the model used to compute the safe trajectory is based upon the three layers driver model developed in [1]. At higher level, the trajectory is very generic and only interact with long range information to optimize the path (for instance with the use of traffic information). At the middle level, the trajectory deals with the direct environment of the vehicle up to few hundred meters (for instance, the definition of speed and lane). At the lower level, the trajectory is generated for the next seconds and directly interact with the actuators. At the middle level, we can handle a strong cooperation with the driver as the system delivers outputs as recommended speed, or recommended manoeuvre (stay in lane, lane change ...). The proposed algorithm can also delivers the most risky object in the environment. Moreover, it is simple to fit on a vehicle ECU.

The sequel of the document is organized as follow. In the second section, a brief overview of the objectives is presented. It develops the interaction with the driver. Third section focuses on the core of the system, the risk evaluation, the decision algorithm and the interaction with control theory. Next section explains the proposed algorithm on two cases, the speed regulation and the lane changing decision. Finally, we conclude in the last section.

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II. Driver and Model

A. Objectives of the model

Objectives of the proposed decision algorithm is twofold. First, as seen previously, objective is to decide which action, or succession of action is the best to achieve a risk decrease. This use is mainly intended for a driving assistance or a driving control. Next, comparing the reaction of a virtual pilot with a real pilot and learning the difference, it could possible to monitor the driver and warn him on possible dangerous actions.

Research on driver model and decision tends to agree on a definition of the driver on a multi layer models. Each layer has a specific decision process and is only directly connected to the upper and lower levels. The model proposed in [1] is particularly interesting. At the upper level, the driver take long range decision, this decision will affect the choice of the road and of the current lane. The task realized at the intermediate level is to decide, according to the upper layer what will be the actions to do in the next seconds (ranging up to $10s$). The lower layer realizes the actions decided and also generates feedbacks accordingly to the close environment and to the haptic connection with the vehicle (lateral and longitudinal acceleration, vehicle vibration, steering wheel self aligning torque...). Figure 1 shows this layer representation of the driver and data flow, according to the environment sensed. Global reaction time for the three layers is hard to know. However, literacy on this topic shows that the two first levels have a mean reaction time about $1s$ to $1.2s$ depending on the driver and the lower level has a reaction time of $0.5s$.

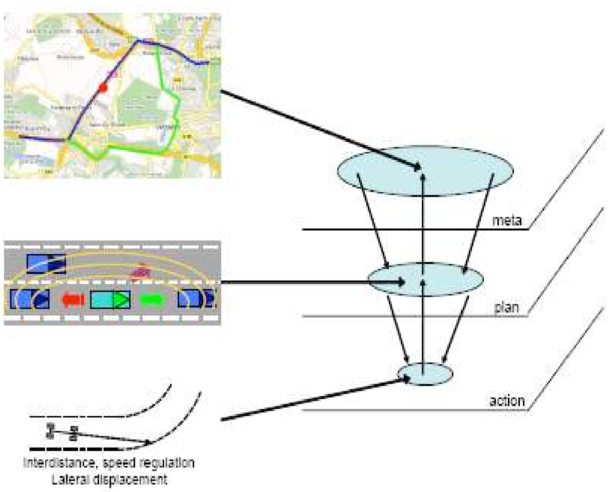

Fig. 1. three layers description of the driver, data flow and environment sensed

This three layers model fits well the development in control theory and has already been adapted in the frame of the Prevent European Project. The upper layer takes into account long range information as traffic data, motivation of the trip and generate global values to achieve : an average trip duration, speed realization and route planning. The intermediate level uses to sense the environment a local map with position of surrounding vehicles, vulnerable road user and lane position. It also takes into account data from others layers. As outputs, this level generates both speed and manoeuver recommendation. The lower layer takes as inputs manoeuver and speed to achieve from higher layers, and an accurate description of the close vicinity, including the road.

The second layer has the advantage to generate a possible vehicle manoeuver, which is the topic of this article. The possible manoeuver can also be used in order to compare the driver desired trajectory and the algorithm choice. In the frame of the HAVE-IT European project, the model will also be used for this task. Figure 2 shows the comparison between driver choice and algorithm. When the difference is too large the system can act and decides to override the driver command to keep the vehicle in a safe area according to the environment and the vehicle dynamic.

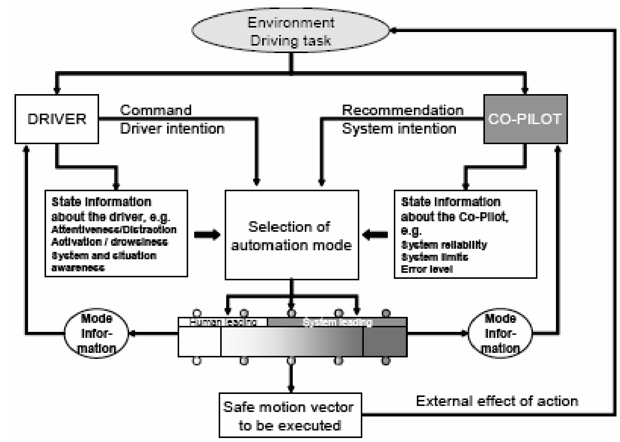

Fig. 2. Driver and Algorithm comparison (HAVE-IT Project)

B. Adaptation of the three layers driver model

The three layers driver model, described by [1], requires few adaptations in order to described a pilot reaction in term of automatic control. These adaptations mainly rely on the definition of parameters at each level. The following describes the parameter attached to each level.

At the lowest level, the virtual pilot executes the manoeuver defined at the upper layer. The execution is mainly a matter of actuators control with respect to the close environment. It is defined using limitation in term of vehicle dynamic solicitation as lateral and longitudinal acceleration, and short "action" reaction time. To be closer to the driver definition, the lowest layer can also uses a limitation in term of steering angle ratio.

At the middle layer, the virtual pilot defines the vehicle trajectory in term of lane following or lane changing according to the evaluation of the environment. In order to choose between different possibilities, the virtual pilot assess a risk level with respect to each object in the vicinity. The computation of the risk uses parameters as maximal possible deceleration or acceleration, inter vehicular time and minimal inter vehicular distance. The definition of the trajectory must also take into account the generic path that has been decided and the different objectives fixed by the upper level.

At the higher level, the virtual pilot takes into account long range information in order to define the path to reach the driver objectives. This level also computes the acceptable risk for the lower layer. This computation uses the deviation from the driver objectives, as a time duration for the trip, to assess parameters as speed limit or risk gap to cross a line.

III. Trajectory definition and risk evaluation

Common approach in risk theory is to define the risk related to an event using two criteria :

– The probability that the event occurs,
– The gravity of the resulting situation under the assumption that the events occurs.

In the definition of a virtual pilot, the event that the algorithm want to avoid is a collision. Given the various situations that a generic algorithm must take into account, we have made the assumption that we are considering only the first collision and not the other crashes caused by the initial impact. Moreover, the virtual pilot objectives in the second layer is to define the possible trajectory, either remaining in the same lane or changing. Thus, we are mainly looking for rear-end collisions between two vehicles.

A. *Crash severity*

Between the probability and the gravity, this last parameter is the easier to assess. The severity of a collision has been extensively studied and often use the equivalent energetic speed (namely EES, [7]) during the collision. EES corresponds to the deformation energy of a damaged vehicle during a collision given their respective speed and mass. It is directly linked with the damage done to the human in the vehicle. The speed can be computed using the following equations :

$$\begin{cases} MV + M_iV_i = M\hat{V} + M_i\hat{V}_i \\ \frac{1}{2}MV^2 + \frac{1}{2}M_iV_i^2 = \frac{1}{2}M\hat{V}^2 + \frac{1}{2}M_i\hat{V}_i^2 \end{cases} \quad (1)$$

In these equations, the indices X_i is related to the considered vehicle and the $\hat{X}$ represents the variables after the collision. The EES of the vehicle is then :

$$EES = \hat{V} - V = \frac{2M_i}{M + M_i}(V_i - V) \quad (2)$$

Using data on EES and probability of injuries, we can define a scale of severity relative to the probability of light injury, heavy injury or fatality. Figure 3 represents the likelihood of a moderate injury (MAIS¿2, Maximum Abbreviated Injury Scale) with respect to the EES. The resulting probability of injury is used as the gravity part of the risk in the following.

B. *Assessing a probability of collision*

In order to assess the probability of collision, we use parameters describing the longitudinal driver behavior.

First parameter is relative to the Time To Collision. Hayward [2] defined TTC as : *The time required for two vehicles to collide if they continue at their present speed and on the same path*. The TTC formula is :

$$TTC = \frac{D_i}{V - V_i} \quad (3)$$

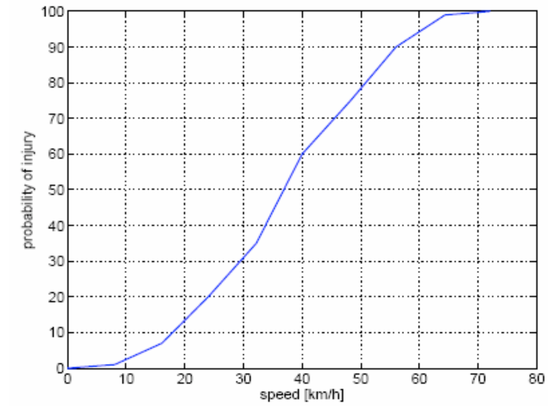

Fig. 3. EES and MAIS scale for a sever injury

In this formula, D_i is the distance with the vehicle i. Project as ARCOS (www.arcos2004.fr) and PREVENT (www.prevent-ip.org) have studied TTC and give boundaries on the behavior of driver, or automated system, with respect to the following values :

– at a TTC of $10s$, the vehicle i is supposed to have no interaction,
– a TTC of $1.5s$ is commonly used to trigger a first level of warning,
– when the TTC goes below $1.3s$ the system can strengthen the warning
– if the TTC becomes lower than $1s$ an automatic system can be triggered

We use the two extreme values to determine a probability of collision of 1 (for a TTC of $10s$) and 0 (for a TTC below $1s$). Between these values the probability is linear with respect to the TTC. Figure 4 represents the evaluation of the probability.

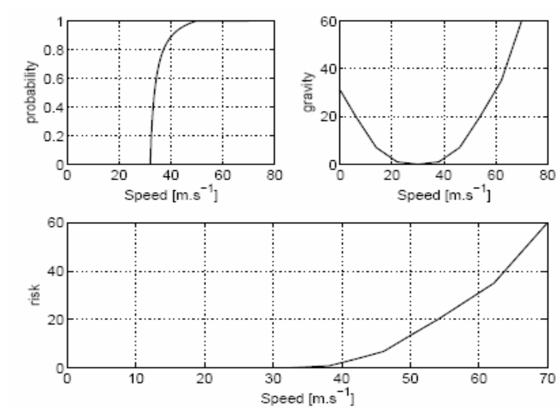

Fig. 4. TTC probability of collision, gravity and resulting risk

In this figure, the vehicular inter distance is $20m$, the leading vehicle speed is $30ms^{-1}$ and the masses are set at $1500kg$.

C. *A complete risk*

The risk is evaluated using the two previous components, as shown in figure 4, which results on the multiplication of the probability with the gravity. However this definition of probability part of the risk with respect to the TTC is not sufficient as the TTC could be large even with an inter vehicular distance small, which is a risky situation. We enhance this definition with a criteria representing assessing this specific risk on a emergency braking scenario. In this scenario, the vehicle i brakes with a deceleration γ_i. After a reaction time T_r the considered vehicle brake with a deceleration γ. The first possibility is that the vehicles collide without any reaction from the considered vehicle, the upper limit of the distance, D_{nr}, and the difference of speed, ΔV, are :

$$\begin{cases} D_{nr} = (V - V_i)\, T_r + \frac{\gamma_i}{2} T_r^2 \\ \Delta V = V - V_i + \gamma_i T \end{cases} \quad (4)$$

If the distance between the two vehicles is greater than D_{nr}, a collision may always occurs if the vehicle are too close. The speed difference is then :

$$\Delta V = V - V_i + (\gamma_i - \gamma) T + \gamma T_r \quad (5)$$

If the decelerations of the two vehicles are close, from the two previous equation, we can say that additional risk is mainly resulting of the parameter γT_r. As previously, we define a transfer function between the inter distance and the additional risk. The result is given by figure 5. The maximal distance D_r is set at VT_r. On the right part of the figure, we have searched the maximal speed minimizing the risk in the following scenario : the distance of the two vehicles is $20m$ and the speed of the vehicle i is $30ms^{-1}$. With the first evaluation, the resulting speed will be $30ms^{-1}$, leading to a risky situation. The second evaluation gives a speed of $20ms^{-1}$.

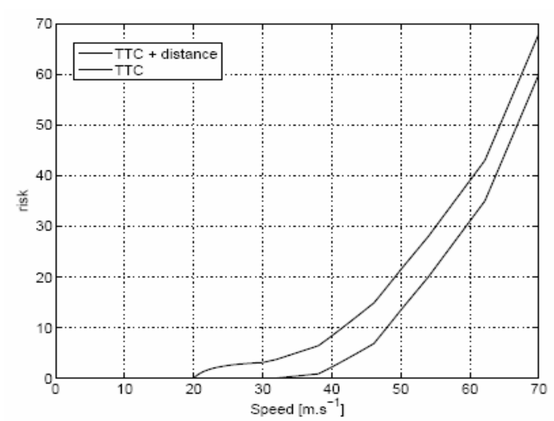

Fig. 5. Enhanced risk criteria and resulting risk

D. Evaluation in a lane

In order to define the safe speed for the vehicle, the virtual pilot assesses a risk for each vehicle in the lane and for each possible speed. Then, the different risks are added. The virtual pilot looks for the safest speed, some possibilities arise :

- The safest speed is unique and close to the driver desired speed,
- The safest speed is unique but far from the driver desired speed, then, the virtual pilot chooses this speed, but he accumulate a negative cost at the upper layer of the driver model,
- The safest speed is not unique, then, the virtual pilot try to match his objectives at the best.

The accumulation of negative cost at higher level may lead to a modification in the objectives of the driver.

When the virtual pilot must face a multiple lanes road, he also evaluates, using the same principle the risk in each adjacent lane. The decision to engage a lane change manoeuvre instead of staying in the current lane is taken using the following principle :

- The virtual pilot already achieve the target speed, but he can do it with a lower risk on another lane,
- The virtual pilot can not achieve the target speed, and can achieve it or at least be closer to the target speed.

In order to avoid behavior as continuous lane change, the risk difference between two lanes is set at a minimal value that describe the virtual pilot type.

IV. Application examples

In the following, we described two applications. First one corresponds to a speed regulation example, second one deals with a lane change manoeuvre.

A. Vehicle following

Choosing the maximal speed with minimal risk, Figure 4 and 5 clearly shows that at the limit, we will have a speed that is equal to the following vehicle. One more interesting simulation is to evaluate the approach on a slow moving vehicle. In order to evaluate this scenario, we suppose that our vehicle drives at $40ms^{-1}$ ($144km/h$) and the front vehicle is at 300m with a speed of $20ms^{-1}$ ($72km/h$). The controlled vehicle will drive at the maximal safest speed. Figure 6 shows the resulting speed. At the beginning, the vehicle is too far to have an impact on our vehicle, so the speed remains constant, after $T = 6s$, front vehicle starts to have an impact on the risk evaluation of our vehicle, corresponding to a decrease in speed. After $T = 25s$, the inter vehicular distance regulate the speed, so a stronger decrease appears. The simulation stop at $T = 27s$ when both vehicle have the same speed with a safe inter vehicular distance.

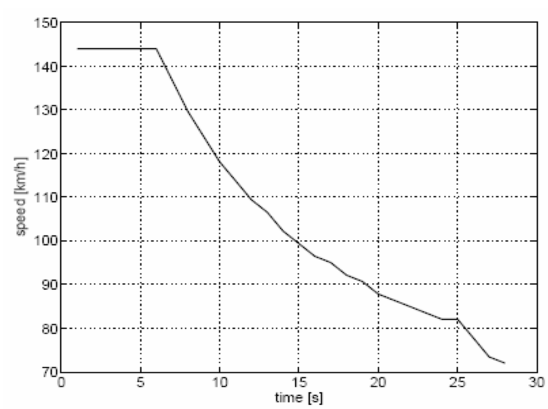

Fig. 6. Fast vehicle approaching scenario

On the whole simulation, the deceleration of the controlled vehicle remains below $0.3g$.

B. Lane Change

In this scenario, we suppose that at the beginning, two vehicles are on the same lane with our vehicle. The front vehicle speed is $20ms^{-1}$ and relative distance is $100m$, rear vehicle speed is $25ms^{-1}$ and the relative distance is also $100m$. Figure 7 shows the speed of our vehicle and relative distance in this scenario. After $T = 30s$ the relative distance with the rear vehicle becomes unacceptable. The risk in this situation is very high, these results are shown on the second row of the figure : in the first case, the choice of speed with a risk of zero is large. In the second case, the speed with minimal risk is set for a non-zero risk.

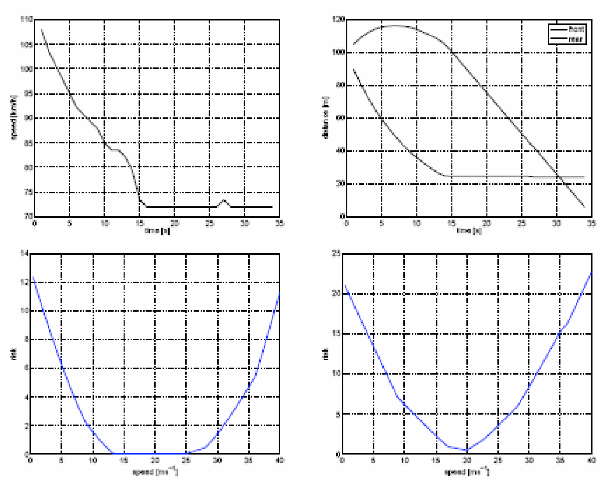

Fig. 7. Three vehicles scenario

At the same time, on the adjacent lane, we compute the risk using the same process, putting a virtual vehicle on this lane at the same curvilinear location. If the risk drop below the risk on our lane, the vehicle will engage a lane change manoeuvre. For instance, if a vehicle is at a relative distance of $100m$ at the beginning of the simulation, and has a speed of $30ms^{-1}$, we compute the risk at the same time than given previously for the second row of figure 7. The results are shown on figure 8. On the first figure, the vehicle is still behind, the risk is high with respect to the current speed of the controlled vehicle. On the second figure, the vehicle is now in front of the considered vehicle, the risk is now really low on a large range of speed, and lower than on its current lane.

V. Conclusion

This article aims to propose an algorithm in order to define possible manoeuver of the vehicle according to the environment. The method could be used twofold. First, it defines the actions that lower level algorithms can do to keep the vehicle in a safe area. Next, as the outputs of the algorithm is set at an higher level, it could be compared with the actions that the driver does. This comparison can be used in order to decide which entity has the vehicle control.

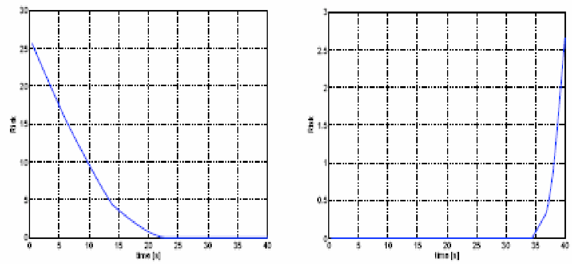

Fig. 8. Adjacent lane risk evaluation

Even if the final information at this level is less rich that it could be with methods from robotics, the main advantage is the speed of the computation needed for the decision of the virtual pilot. It ensures a fast answer to the environment modifications, with low computation and low memory usage.

The algorithm is evaluated on two scenarios. It shows to be coherent with common driving reaction. Even if the definition of the manoeuver gives less information than methods from robotics, the computation is fast and can be used in real time in a vehicle at a fast refresh rate. Moreover, the data required to compute the risk is easily achievable, as we only need relative distance and speed of considered objects.

Following works will be focused on the link with vehicle control to achieve the desired manoeuvre. Also, we will compared different strategies on the realization of the virtual pilot as method based on fuzzy logic or potential field.

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